

BEST AVAILABLE COPY

(12) UK Patent Application (19) GB (11) 2 365 899 (13) A

(43) Date of A Publication 27.02.2002

(21) Application No 0120044.3

(22) Date of Filing 16.08.2001

(30) Priority Data

(31) 09640219

(32) 16.08.2000

(33) US

(71) Applicant(s)

Smith International, Inc  
(Incorporated in USA - Texas)  
16740 Hardy Street, Houston, Texas 77032,  
United States of America

(72) Inventor(s)

Amardeep Singh  
Sujian Huang  
Scott McDonough

(74) Agent and/or Address for Service

Kilburn & Strobe  
20 Red Lion Street, LONDON, WC1R 4PJ,  
United Kingdom

(51) INT CL<sup>7</sup>

E21B 10/16

(52) UK CL (Edition T)

E1F FFD

(56) Documents Cited

GB 2360304 A

WO 00/12860 A2

US 5730234 A

GB 2328966 A

WO 00/12859 A2

US 5197555 A

(58) Field of Search

UK CL (Edition S) E1F FFD FGE

INT CL<sup>7</sup> E21B 10/16 10/62

Online: EPODOC, WPI & JAPIO

(54) Abstract Title

Roller cone drill bit having non-axisymmetric cutting elements oriented to optimise drilling performance

(57) At least one cutting tooth 29 with a crest without rotational symmetry is located on the rolling cone of a drill bit. The drilling performance of this bit in a selected lithology is simulated and the orientation  $\theta_1$  of the asymmetrical tooth is adjusted and the simulation iteratively repeated until the optimum orientation has been determined. This is associated either with the peak value of a single performance parameter, such as the rate of bit penetration, or with the orientation that offers best performance as measured by a combination of parameters. A typical optimum orientation is about 25° perpendicular to the plane containing both the cone axis and the tooth. The orientation of the base of the tooth may also be optimised in the same way and need not match the orientation of the tooth crest (figure 4). Also disclosed is a rolling cone with at least one tooth at a different orientation to the rest, in order to prevent tracking.

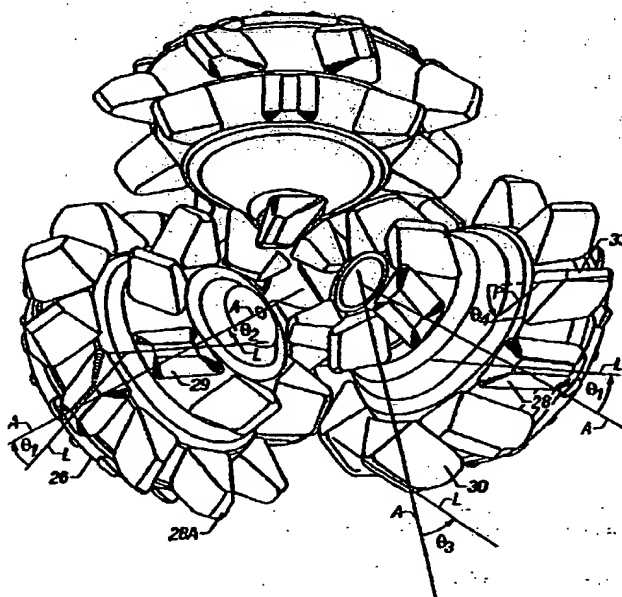
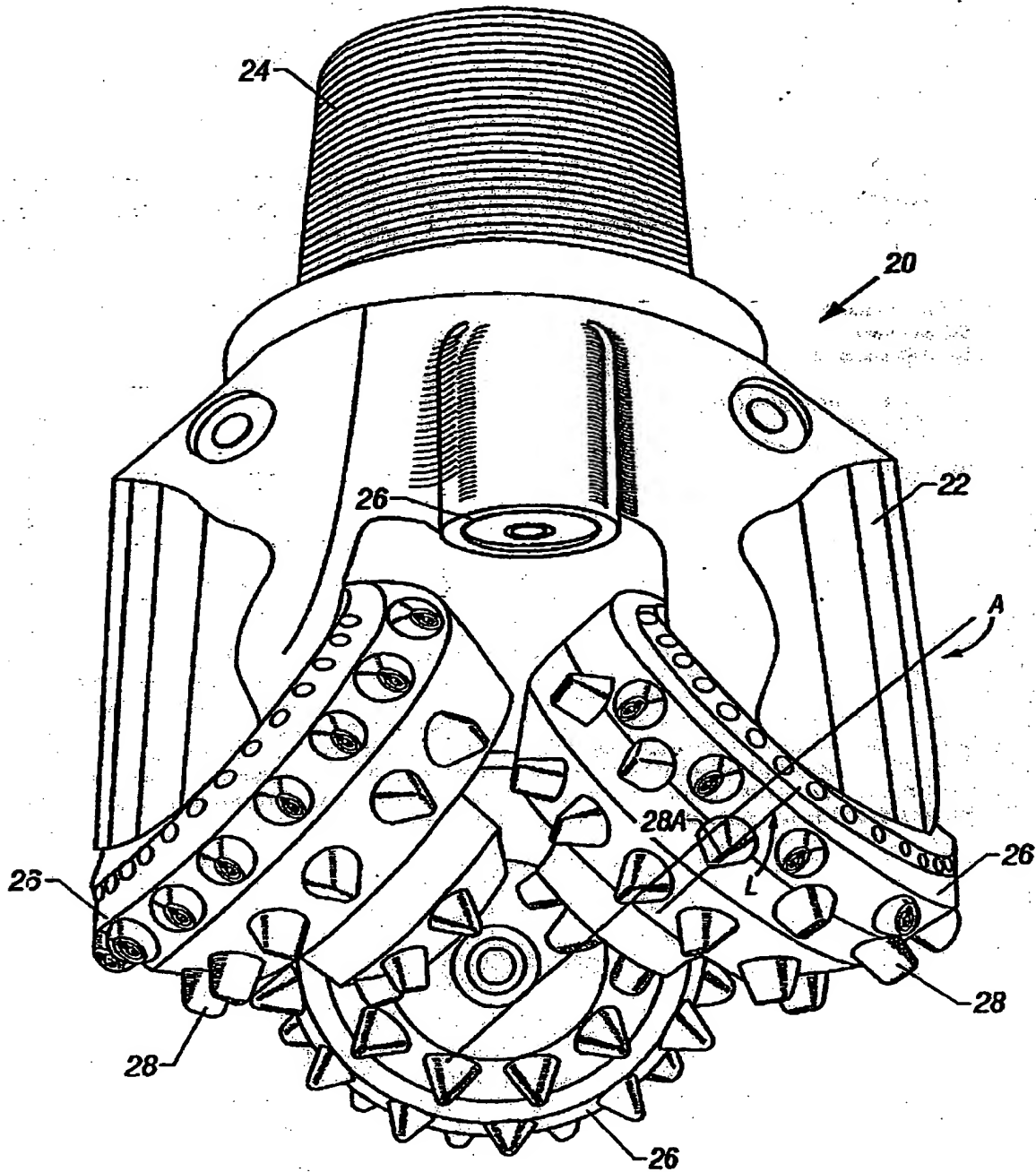


FIG. 2

GB 2 365 899 A



1/3



**FIG. 1**  
**(Prior Art)**



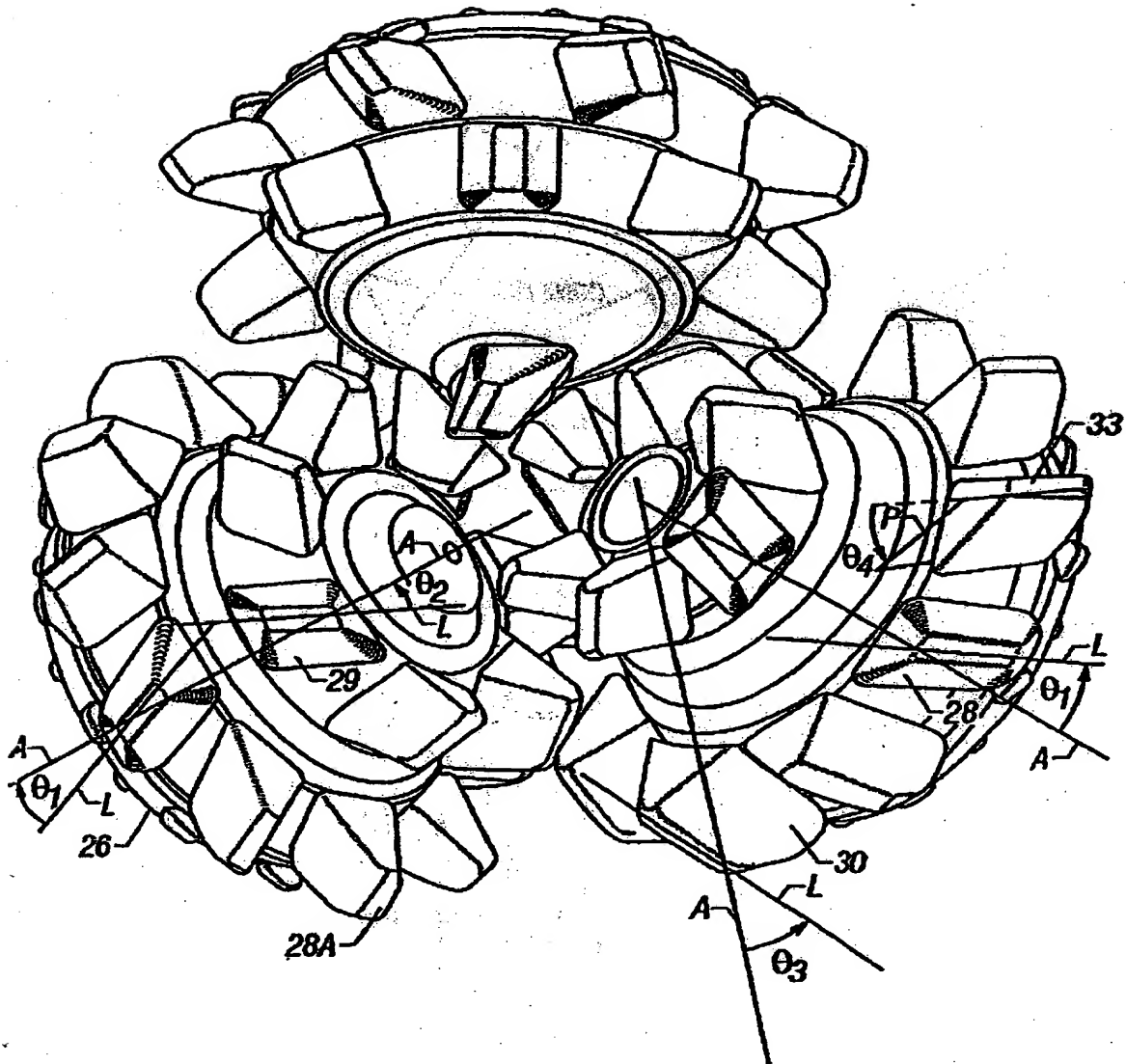
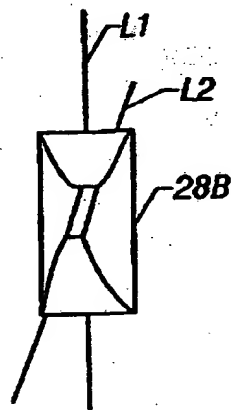
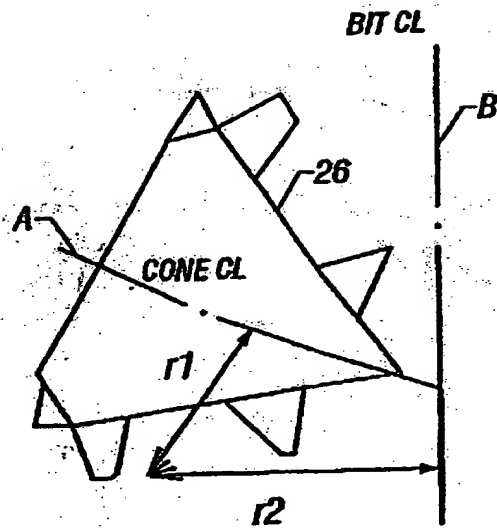


FIG. 2



3/3





**ROLLER CONE DRILL BIT HAVING NON-AXISYMMETRIC  
CUTTING ELEMENTS ORIENTED TO OPTIMIZE DRILLING  
PERFORMANCE**

The invention relates generally to the field of drill bits used to drill earth formations. More specifically, the invention relates to methods for designing, and  
5 to designs, for drill bits having improved drilling performance.

Roller cone drill bits used to drill wellbores through earth formations generally include a plurality of roller cones rotatably mounted to a bit body. The bit body is turned by a drilling apparatus (drilling rig) while axial force is applied  
10 to the bit to drill through the earth formations. The roller cones include a plurality of cutting elements disposed at selected locations thereon. The types, sizes and shapes of the cutting elements are generally selected to optimize drilling performance of the drill bit in the particular earth formations through which the formation is to be drilled.

15 The cutting elements may be formed from the same piece of metal as each of the roller cones, these being so-called "milled tooth" bits. Other types of cutting elements consist of various forms of "inserts" (separate bodies formed from selected materials) which can be affixed to the roller cones in a number of different ways.

20 Some types of cutting elements, both milled tooth and insert type, have cutting edges ("crests") which are not symmetric with respect to an axis within the body of the cutting element. These are called non-axisymmetric cutting elements. Some types of roller cone drill bits have non-axisymmetric cutting elements



oriented so that the crests are oriented in a selected direction. The purpose of such crest orientation is to improve the drilling performance of the roller cone bit.

One such method for improving drill bit performance by orienting cutting element crests along a particular direction is described in published patent application PCT/US99/19992 filed by S. Chen. The method disclosed in this application generally includes determining an expected trajectory of the cutting elements as they come into contact with the earth formation. The expected trajectory is determined by estimating a rotation ratio of the roller cones, this ratio being the cone rotation speed with respect to the bit rotation speed. The crests of the cutting elements are then oriented to be substantially perpendicular to, or along, the expected trajectory. Whether the crests are oriented perpendicular or along the expected trajectory depends on the type of earth formation being drilled.

Yet another method for orienting the crests of the cutting elements on a roller cone bit is described in U. S. patent no. 5,197,555 issued to Estes. As explained in the Estes '555 patent, the crests of the cutting elements are oriented within angle ranges of 30 to 60 degrees (or 300 to 330 degrees) from the axis of rotation of the cone.

It is desirable to provide a drill bit wherein non-axisymmetric cutting elements are oriented to optimize a rate at which the drill bit cuts through earth formations.

One aspect of the invention is a roller cone drill bit having roller cones rotatably attached to a bit body. Each of the cones includes a plurality of cutting elements, at least one of the cutting elements being non-axisymmetric and oriented



so that a value of at least one drilling performance parameter is optimized. In one embodiment, the at least one parameter include rate of penetration of the drill bit.

5 In one embodiment, the crest of the at least one cutting element is oriented at an angle of about 10 to 25 degrees from the direction of movement of the cutting element as it contacts the earth formation when the cutting element is disposed in a position outboard of the drive row location on the cone. In another embodiment, the angle is about 350 to 335 degrees when the cutting element is disposed in a position inboard of the drive row location.

10 Another aspect of the invention is a method for designing a roller cone drill bit including simulating the bit drilling earth formations. The drill bit includes roller cones rotatably attached to a bit body. Each of the cones includes a plurality of cutting elements, at least one of the cutting elements being non-axisymmetric. In the method, an orientation of the cutting element is adjusted, and the drilling is again simulated. The adjustment and simulation are repeated until the value of at  
15 least one drilling performance parameter is optimized. In one embodiment, the at least one performance parameter includes the rate of penetration of the drill bit.

Other aspects and advantages of the invention will be apparent from the description which follows.

20

Figure 1 shows one example of a prior art roller cone drill bit having non-axisymmetric cutting elements.

Figure 2 shows a bottom view of one example of a roller cone bit having cutting elements oriented according to the invention.

25 Figure 3 shows one example of how to approximate a location of a drive row on a cone.



Figure 4 shows one embodiment of a cutting element which has more than one direction of a long dimension.

### DETAILED DESCRIPTION OF THE INVENTION

Referring to Figure 1, a typical prior art roller cone drill bit 20 includes a bit body 22 having an externally threaded connection at one end 24, and a plurality of roller cones 26 (usually three as shown) attached to the other end of the bit body 22 and able to rotate with respect to the bit body 22. Attached to the cones 26 of the bit 20 are a plurality of cutting elements 28 typically arranged in rows about the surface of the cones 26. The cutting elements 28 can be any type known in the art, including tungsten carbide inserts, polycrystalline diamond compacts, or milled steel teeth. The cutting elements shown in Figure 1 at 28 are non-axisymmetric, meaning that the crest 28A of the cutting element is not symmetric with respect to an axis (not shown) of the cutting element 28. Typically, the crest 28A of a non-axisymmetric cutting element such as shown at 28 will define a long dimension, shown along line L. An orientation of the long dimension L is generally defined as an angle subtended between the direction of the long dimension L and a selected reference. In this example the reference is the rotational axis of the cone, shown at A. Any other suitable reference can be used to define the orientation of the cutting element. The non-axisymmetric cutting elements 28 on the bit 20 shown in Figure 1 are arranged so that the long dimension L is substantially parallel (at zero degrees subtended angle) with respect to the axis rotation A.

It should be noted that the long dimension L for the crest 28A shown in Figure 1 is substantially parallel to the crest 28A because the crest 28A is linear. Other shapes of crest are known in the art which will have different definitions of the long dimension. For example, crescent shaped crests on some cutting elements



may have the long dimension defined as along a line connecting the endpoints of the crescent. Referring briefly to Figure 4, for example, a special type of cutting element 28B has a long dimension L2 across its crest which as shown in this example is oriented differently than the long dimension L1 of the base of the cutting element 28B. For the description of the invention which follows, the orientation of the crest of such cutting elements will be determined by the direction of L2. As will be further explained, the individual orientation of both L2 and of L1 can be optimized to provide improved drilling performance.

Referring back to Figure 1, although the bit 20 has been shown wherein substantially all the cutting elements 28 include the long dimension L, it is within the scope of this invention if only one such cutting element, or any other number of such cutting elements, is non-axisymmetric and includes long dimension L. The rest of the cutting elements may be axisymmetric. Therefore, the number of non-axisymmetric cutting elements is not intended to limit the invention.

It has been determined that the orientation of the long dimension L with respect to the axis of the cone A has an effect on drilling performance of the bit 20. In one aspect of the invention, drilling with the bit 20 through a selected earth formation is simulated. The simulation typically includes determination of a rate at which the bit penetrates through the selected earth formation (ROP), among other performance measures. In this aspect of the invention, the angle of the long dimension L with respect to the selected reference is adjusted, the drilling simulation is repeated, and the performance of the bit is again determined. The adjustment to the angle and simulation of drilling are repeated until the drilling performance is optimized. In one embodiment of the invention, optimization is determined when the rate of penetration (ROP) is determined to be maximum.

One such method for simulating the drilling of a roller cone drill bit such as shown in Figure 1 is described in U. S. patent application serial no. 09/524,088



filed on March 13, 2000, and assigned to the assignee of this invention. The method of the '088 patent application is hereby incorporated by reference. The method for simulating the drilling performance of a roller cone bit drilling an earth formation may be used to optimize the design of roller cone drill bits, and to  
5 optimize the drilling performance of a roller cone bit. The method includes selecting bit design parameters, selecting drilling parameters, and selecting an earth formation to be drilled. The bit design parameters generally include at least the shape of the cutting elements on the drill bit. The method further includes calculating, from the bit design parameters, drilling parameters and earth  
10 formation, the parameters of a crater formed when one of the cutting elements contacts the earth formation. The method further includes calculating a bottomhole geometry, wherein the crater is removed from a bottomhole surface. The method also includes incrementally rotating the bit and repeating the calculating of crater parameters and bottomhole geometry based on calculated  
15 roller cone rotation speed and geometrical location with respect to rotation of said roller cone drill bit about its axis.

In the present embodiment, the simulation according to the previously described program is performed. At least one drilling performance parameter, which can include the rate of penetration, is determined as a result of the  
20 simulation. The angle of the long dimension  $L$  of the at least one non-axisymmetric cutting element is adjusted. The simulation is repeated, typically including maintaining the values of all the other drilling control and drill bit design parameters, and the value of the at least one drilling performance parameter is again determined. This process is repeated until the value of the drilling  
25 performance parameter is optimized. In one example, as previously explained, the drilling performance parameter is optimized when rate of penetration is determined to be at a maximum.



For the special cutting element 28B shown in Figure 4, the orientation of the crest long dimension L2 and the orientation of the base long dimension L1 can both be adjusted, the simulation repeated, and the results compared until the value of the at least one drilling performance parameter is optimized. It is believed that in some drill bits, the direction of the velocity vector may be different at the crest of the cutting elements than at the base of the cutting elements. Specially shaped cutting elements such as shown at 28B in Figure 4 provide the bit designer with the ability to optimize the orientation of the long dimension at both the crest and at the base of the cutting elements to further improve drilling performance. As for the other embodiments of a bit according to the various aspects of the invention, the number of such special cutting elements as shown in Figure 4 is not meant to limit the scope of the invention.

Another aspect of non-axisymmetric cutting elements is that some types of such cutting elements may not be symmetric with respect to a bisecting plane. Other types of such cutting elements may be symmetric with respect to a bisecting plane. Referring briefly to Figure 1, typical prior art cutting elements such as 28A which are not axisymmetric nonetheless have a bisecting plane about which the cutting element is symmetric. In the prior art, such cutting elements 28A are oriented such that the bisecting plane is substantially perpendicular to the surface of the roller cone. Another aspect of the invention is that in addition to orienting the cutting element crest at a selected angle with respect to the cone axis, the bisecting plane is oriented at a selected angle with respect to the surface of the cone. An example of this orientation is shown in Figure 2, where bisecting plane P subtends an angle  $\theta_4$  with respect to perpendicular to the surface of the cone 26. As with other aspects of the invention, the orientation of the subtended angle  $\theta_4$  is preferably determined by selecting an initial value of the subtended angle, simulating performance of the bit, adjusting the angle, and repeating the



simulating performance until an optimal value of the at least one drilling performance parameter is determined.

Referring to Figure 2, through drilling simulation according to the method described in the '088 patent application, it has been determined that drilling performance of a certain type of roller cone bit known as a tungsten carbide insert (TCI) bit having "chisel" shaped inserts, is optimal when the angle, shown as  $\theta_1$ , of the long dimension L, is in a range of about 10 to about 25 degrees with respect to the axis A, when the cutting element 28 is disposed in a position on the cone radially outboard (away from the center of the cone) of the radial position of a "drive row" on the cone. If the cutting element, for example, as shown at 29, is disposed in a row radially interior to the drive row position, it has been determined that drilling performance is improved when the angle, shown in Figure 2 as  $\theta_2$ , is within a range of about 350 to 335 degrees. The definition of the size of the angle used herein is that the angle increases in a direction of the "leading" edge (toward the direction of rotation of the cone).

It has been determined through simulation of drilling with the bit that a more preferred value for the angle  $\theta_1$  is about 25 degrees, and that a more preferred value for angle  $\theta_2$  is about 335 degrees.

In the event that the cutting element is radially positioned at the drive row location, the angle may be either approximately 10 to 25, or 350 to 335 degrees, (or more preferably 25 or 335 degrees) depending on which value of the angle provides a more optimized value of the drilling performance parameter, such as higher rate of penetration.

One method for estimating the position of the drive row is illustrated in Figure 3. The rotation ratio of each of the cones 26 can be determined, for example, using force calculations such as described in the '088 patent application referred to earlier, or by simulating the drilling of the bit as in the '088 patent



application. Having determined or otherwise estimated the rotation ratio of the cone 26, a ratio of drive row distance  $r_2$  from the axis of the bit B with respect to effective cone radius  $r_1$  will be approximately related to the position of the drive row. The drive row position for purposes of this invention will be located  
5 approximately at the position along the cone axis A where the ratio  $r_2/r_1$  is approximately the same as the rotation ratio of the cone 26. In any particular bit design, there may or may not be a row of cutting elements disposed at the drive row location. The angle for orienting the at least one cutting element can be selected, as previously explained, by considering the location of the at least one  
10 cutting element with respect to the drive row location estimated according to the previously described method.

Referring again to Figure 3, a particular feature of the invention is shown which has as its purpose further improvement of drilling performance. At least one of the cutting elements 30, in a row in which all the other cutting elements are  
15 oriented at the preferred angle  $\theta_1$ , preferably is oriented at a different angle  $\theta_2$ , so that the row of cutting elements will resist "tracking". The magnitude of the difference in the angles is not important, but only need be selected to avoid tracking. In particular, whether the selected difference in angle between the at least one cutting element and the other cutting elements on the same row is enough  
20 to avoid tracking can be determined, among other methods, by using the drilling simulation technique described in the '088 patent application referred to earlier.

This feature of the invention can work with other embodiments of a drill bit. For example, substantially all of the cutting elements on the bit may have long dimension L parallel to the respective axis A of the cone on which each cutting  
25 element is disposed. At least one cutting element on any one row of cutting elements on the bit may be disposed so that its long dimension L subtends an angle other than parallel to the cone axis. In another example, at least one cutting



element on each row on one cone can be disposed so that its long dimension is other than parallel to the respective cone axis. In yet another example, at least one cutting element on each cone, or alternatively, at least one cutting element on each row of each cone can be oriented so that its long dimension is other than parallel to the cone axis. In each of the foregoing examples, orienting the at least one cutting element so that its long dimension other than parallel to the cone, when all the other cutting elements in the same row are parallel to their respective cone axis is intended to reduce tracking. This aspect of the invention will also work where the other ones of the cutting elements on the same row are not parallel to the cone axis but are disposed at some selected angle (such as the previously described preferred angle). As long as at least one cutting element is disposed at a different angle than all the other cutting elements on one row of cutting elements on the bit, such configuration is within the contemplation of this aspect of the invention. In another example, each row of cutting elements on each of the cones includes at least one cutting element disposed at an angle different from all the other cutting elements on the row to avoid tracking.

The invention has been described with respect to particular embodiments. It will be apparent to those skilled in the art that other embodiments of the invention can be devised which do not depart from the spirit of the invention as disclosed herein. Accordingly, the invention shall be limited in scope only by the attached claims.



## CLAIMS

- 1        1.     A method for optimizing drilling performance of a roller cone drill  
2 bit, comprising:  
3        simulating drilling with the bit in a selected earth formation to determine at  
4 least one drilling performance parameter;  
5        adjusting an orientation of at least one non-axisymmetric cutting element  
6 on the bit;  
7        repeating the simulating the drilling and determining the at least one  
8 performance parameter; and  
9        repeating the adjusting and simulating the drilling until the at least one  
10 performance parameter is determined to be at an optimum value.
- 1        2.     The method as defined in claim 1 wherein the at least one  
2 performance parameter comprises a rate of penetration.
- 1        3.     The method as defined in claim 2 wherein the optimum value is  
2 determined when the rate of penetration is at a maximum value.
- 1        4.     The method as defined in claim 3 wherein the optimum value  
2 determined when the orientation is in a range of about 10 to 25 degrees when the  
3 at least one cutting element is disposed outboard of a drive row location on the  
4 cone.
- 1        5.     The method as defined in claim 3 wherein the optimum value is  
2 determined when the orientation is about 25 degrees when the at least one cutting  
3 element is disposed outboard of a drive row location on the cone.



1        6.    The method as defined in claim 3 wherein the optimum value is  
2 determined when the orientation is in a range of about 350 to 335 degrees when  
3 the at least one cutting element is disposed inboard of a drive row location on the  
4 cone.

1        7.    The method as defined in claim 3 wherein the optimum value  
2 determined when the orientation is about 335 degrees when the at least one cutting  
3 element is disposed inboard of a drive row location on the cone.

1        8.    The method as defined in claim 1 wherein an orientation of a crest of  
2 the at least one non-axisymmetric cutting element is adjusted separately from an  
3 orientation of a base of the at least one non-axisymmetric cutting element to  
4 optimize the value of the at least one drilling performance parameter.

1        9.    The method as defined in claim 1 further comprising:  
2        adjusting an angle of a bisecting plane of the at least one non-axisymmetric  
3 cutting element with respect to a surface of a roller cone on which the at least one  
4 non-axisymmetric cutting element is disposed;  
5        repeating the simulating and determining; and  
6        repeating the adjusting the bisecting plane angle, simulating and  
7 determining until the optimal value of the at least one drilling performance  
8 parameter is determined to be at the optimal value.



1           10.    A roller cone drill bit, comprising:  
2                a plurality of roller cones, each rotatably mounted on a bit body;  
3                a plurality of cutting elements on each of the cones, at least one of  
4   the cutting elements being non-axisymmetric; and  
5                wherein an angle subtended between a long dimension of the at least  
6   one non-axisymmetric cutting element and an axis of rotation of the cone on  
7   which the at least one cutting element is disposed is selected to optimize a value of  
8   at least one drilling performance parameter.

1           11.    The roller cone drill bit as defined in claim 10 wherein the at least  
2   one drilling performance parameter comprises rate of penetration of the bit.

1           12.    The roller cone drill bit as defined in claim 10 wherein the angle is  
2   approximately 10 to 25 degrees when the at least one cutting element is disposed  
3   outboard of a drive row location on the cone.

1           13.    The roller cone drill bit as defined in claim 10 wherein the angle is  
2   approximately 25 degrees when the at least one cutting element is disposed  
3   outboard of a drive row location on the cone.

1           14.    The roller cone drill bit as defined in claim 10 wherein the angle is  
2   approximately 350 to 335 degrees when the at least one cutting element is  
3   disposed inboard of the drive row location.

1           15.    The roller cone drill bit as defined in claim 10 wherein the angle is  
2   approximately 335 degrees when the at least one cutting element is disposed  
3   inboard of the drive row location.



1        16.    The roller cone drill bit as defined in claim 10 wherein the angle is  
2 the one of approximately 25 degrees and approximately 335 degrees which  
3 provides a higher rate of penetration, when the at least one cutting element is  
4 disposed on a drive row location on the cone.

1        17.    The roller cone drill bit as defined in claim 10 wherein the cutting  
2 elements comprise milled steel teeth.

1        18.    The roller cone drill bit as defined in claim 10 wherein the cutting  
2 elements comprise tungsten carbide inserts.

1        19.    The roller cone drill bit as defined in claim 10 wherein the cutting  
2 elements comprise polycrystalline diamond compacts.

1        20.    The roller cone drill bit as defined in claim 10 wherein at least one  
2 cutting element in a row having cutting elements oriented at the subtended angle is  
3 disposed at a different angle whereby the drill bit substantially avoids tracking.

1        21.    The roller cone drill bit as defined in claim 10 wherein an angle  
2 subtended between a long dimension of a crest of the at least one non-  
3 axisymmetric cutting element and an axis of rotation of the cone on which the at  
4 least one cutting element is disposed, and an angle subtended between a long  
5 dimension of the base of the non-axisymmetric cutting element and the axis of the  
6 cone are both selected to optimize a value of the at least one drilling performance  
7 parameter.



1        22.    The roller cone drill bit as defined in claim 21 wherein the at least  
2 one drilling performance parameter comprises rate of penetration of the bit.

1        23.    The roller cone as defined in claim 10 wherein an angle subtended  
2 between a bisecting plane of the at least one non-axisymmetric cutting element  
3 and a surface of the cone on which the at least one non-axisymmetric cutting  
4 element is disposed is selected to optimize the value of the at least one drilling  
5 performance parameter.

1        24.    The roller cone drill bit as defined in claim 23 wherein the at least  
2 one drilling performance parameter comprises rate of penetration of the bit.

1        25.    A roller cone drill bit, comprising:  
2                a plurality of roller cones rotatably mounted on a bit body; and  
3                a plurality of non-axisymmetric cutting elements disposed on each of  
4 the roller cones, on at least one row of the cutting elements there being at least one  
5 of the cutting elements oriented at a different angle than the other ones of the  
6 cutting elements on the at least one row of cutting elements.

1        26.    The roller cone drill bit as defined in claim 25 further comprising, on  
2 each of the roller cones, at least one cutting element being oriented at an angle  
3 different than the other ones of the cutting elements on the at least one row of the  
4 cutting elements.



1        27.    The roller cone drill bit as defined in claim 26 further comprising, on  
2 each one of the rows on at least one cone, at least one cutting element in each one  
3 of the rows row being oriented at an angle different than the other ones of the  
4 cutting elements in a same one of the rows.

1        28.    The roller cone drill bit as defined in claim 26 further comprising at  
2 least one cutting element in each row on each of the roller cones being oriented at  
3 an angle different than the other ones of the cutting elements on each same row on  
4 each of the roller cones.

1        29.    The roller cone drill bit as defined in claim 26 wherein each of the  
2 other ones of the cutting elements is oriented so that its long dimension is  
3 substantially parallel to an axis of the one of the one of the roller cones on which it  
4 is disposed.

1        30.    The roller cone drill bit as defined in claim 29 wherein each of the  
2 other ones of the cutting elements is oriented so that its long dimension is  
3 substantially parallel to an axis of the one of the one of the roller cones on which it  
4 is disposed.





INVESTOR IN PEOPLE

Application No: GB 0120044.3  
Claims searched: 1-24

Examiner: Andrew Hughes  
Date of search: 11 December 2001

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.S): E1F FFD, FGE

Int CI (Ed.7): E21B 10/16, 10/62

Other: Online: EPODOC, WPI & JAPIO

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A, P	GB 2360304 A (SMITH INTERNATIONAL)	1-3, 10, 11, 17-20
A	GB 2328966 A (SMITH INTERNATIONAL) figure 13a	
A	WO 00/12859 A2 (HALLIBURTON)	
X	WO 00/12860 A2 (HALLIBURTON) whole document	
A	US 5730234 A (INSTITUT FRANCAIS DU PETROLE)	
A	US 5197555 A (ROCK BIT INTERNATIONAL)	

X Document indicating lack of novelty or inventive step  
Y Document indicating lack of inventive step if combined with one or more other documents of same category.

& Member of the same patent family

A Document indicating technological background and/or state of the art.  
P Document published on or after the declared priority date but before the filing date of this invention.  
E Patent document published on or after, but with priority date earlier than, the filing date of this application.



Q. OF INCHES	RADIUS	DEPTH	TURNING
TO	OF	OF MILL	OF CUT
1/2	1/2	1/2	1/2
1/4	1/4	1/4	1/4
1/8	1/8	1/8	1/8
1/16	1/16	1/16	1/16
1/32	1/32	1/32	1/32
1/64	1/64	1/64	1/64
1/128	1/128	1/128	1/128
1/256	1/256	1/256	1/256
1/512	1/512	1/512	1/512
1/1024	1/1024	1/1024	1/1024
1/2048	1/2048	1/2048	1/2048
1/4096	1/4096	1/4096	1/4096
1/8192	1/8192	1/8192	1/8192
1/16384	1/16384	1/16384	1/16384
1/32768	1/32768	1/32768	1/32768
1/65536	1/65536	1/65536	1/65536
1/131072	1/131072	1/131072	1/131072
1/262144	1/262144	1/262144	1/262144
1/524288	1/524288	1/524288	1/524288
1/1048576	1/1048576	1/1048576	1/1048576
1/2097152	1/2097152	1/2097152	1/2097152
1/4194304	1/4194304	1/4194304	1/4194304
1/8388608	1/8388608	1/8388608	1/8388608
1/16777216	1/16777216	1/16777216	1/16777216
1/33554432	1/33554432	1/33554432	1/33554432
1/67108864	1/67108864	1/67108864	1/67108864
1/134217728	1/134217728	1/134217728	1/134217728
1/268435456	1/268435456	1/268435456	1/268435456
1/536870912	1/536870912	1/536870912	1/536870912
1/1073741824	1/1073741824	1/1073741824	1/1073741824
1/2147483648	1/2147483648	1/2147483648	1/2147483648
1/4294967296	1/4294967296	1/4294967296	1/4294967296
1/8589934592	1/8589934592	1/8589934592	1/8589934592
1/17179869184	1/17179869184	1/17179869184	1/17179869184
1/34359738368	1/34359738368	1/34359738368	1/34359738368
1/68719476736	1/68719476736	1/68719476736	1/68719476736
1/137438953472	1/137438953472	1/137438953472	1/137438953472
1/274877906944	1/274877906944	1/274877906944	1/274877906944
1/549755813888	1/549755813888	1/549755813888	1/549755813888
1/1099511627776	1/1099511627776	1/1099511627776	1/1099511627776
1/2199023255552	1/2199023255552	1/2199023255552	1/2199023255552
1/4398046511104	1/4398046511104	1/4398046511104	1/4398046511104
1/8796093022208	1/8796093022208	1/8796093022208	1/8796093022208
1/17592186044416	1/17592186044416	1/17592186044416	1/17592186044416
1/35184372088832	1/35184372088832	1/35184372088832	1/35184372088832
1/70368744177664	1/70368744177664	1/70368744177664	1/70368744177664
1/140737488355328	1/140737488355328	1/140737488355328	1/140737488355328
1/281474976710656	1/281474976710656	1/281474976710656	1/281474976710656
1/562949953421312	1/562949953421312	1/562949953421312	1/562949953421312
1/1125899906842624	1/1125899906842624	1/1125899906842624	1/1125899906842624
1/2251799813685248	1/2251799813685248	1/2251799813685248	1/2251799813685248
1/4503599627370496	1/4503599627370496	1/4503599627370496	1/4503599627370496
1/9007199254740992	1/9007199254740992	1/9007199254740992	1/9007199254740992
1/18014398509481984	1/18014398509481984	1/18014398509481984	1/18014398509481984
1/36028797018963968	1/36028797018963968	1/36028797018963968	1/36028797018963968
1/72057594037927936	1/72057594037927936	1/72057594037927936	1/72057594037927936
1/144115188075855872	1/144115188075855872	1/144115188075855872	1/144115188075855872
1/288230376151711744	1/288230376151711744	1/288230376151711744	1/288230376151711744
1/576460752303423488	1/576460752303423488	1/576460752303423488	1/576460752303423488
1/1152921504606846976	1/1152921504606846976	1/1152921504606846976	1/1152921504606846976
1/2305843009213693952	1/2305843009213693952	1/2305843009213693952	1/2305843009213693952
1/4611686018427387904	1/4611686018427387904	1/4611686018427387904	1/4611686018427387904
1/9223372036854775808	1/9223372036854775808	1/9223372036854775808	1/9223372036854775808
1/18446744073709551616	1/18446744073709551616	1/18446744073709551616	1/18446744073709551616
1/36893488147419103232	1/36893488147419103232	1/36893488147419103232	1/36893488147419103232
1/73786976294838206464	1/73786976294838206464	1/73786976294838206464	1/73786976294838206464
1/147573952589676412928	1/147573952589676412928	1/147573952589676412928	1/147573952589676412928
1/295147905179352825856	1/295147905179352825856	1/295147905179352825856	1/295147905179352825856
1/590295810358705651712	1/590295810358705651712	1/590295810358705651712	1/590295810358705651712
1/1180591620717411303424	1/1180591620717411303424	1/1180591620717411303424	1/1180591620717411303424
1/2361183241434822606848	1/2361183241434822606848	1/2361183241434822606848	1/2361183241434822606848
1/4722366482869645213696	1/4722366482869645213696	1/4722366482869645213696	1/4722366482869645213696
1/9444732965739290427392	1/9444732965739290427392	1/9444732965739290427392	1/9444732965739290427392
1/18889465931478580854784	1/18889465931478580854784	1/18889465931478580854784	1/18889465931478580854784
1/37778931862957161709568	1/37778931862957161709568	1/37778931862957161709568	1/37778931862957161709568
1/75557863725914323419136	1/75557863725914323419136	1/75557863725914323419136	1/75557863725914323419136
1/151115727451828646838272	1/151115727451828646838272	1/151115727451828646838272	1/151115727451828646838272
1/302231454903657293676544	1/302231454903657293676544	1/302231454903657293676544	1/302231454903657293676544
1/604462909807314587353088	1/604462909807314587353088	1/604462909807314587353088	1/604462909807314587353088
1/1208925819614629174706176	1/1208925819614629174706176	1/1208925819614629174706176	1/1208925819614629174706176
1/2417851639229258349412352	1/2417851639229258349412352	1/2417851639229258349412352	1/2417851639229258349412352
1/4835703278458516698824704	1/4835703278458516698824704	1/4835703278458516698824704	1/4835703278458516698824704
1/9671406556917033397649408	1/9671406556917033397649408	1/9671406556917033397649408	1/9671406556917033397649408
1/19342813113834066795298816	1/19342813113834066795298816	1/19342813113834066795298816	1/19342813113834066795298816
1/38685626227668133590597632	1/38685626227668133590597632	1/38685626227668133590597632	1/38685626227668133590597632
1/77371252455336267181195264	1/77371252455336267181195264	1/77371252455336267181195264	1/77371252455336267181195264
1/154742504910672534362390528	1/154742504910672534362390528	1/154742504910672534362390528	1/154742504910672534362390528
1/309485009821345068724781056	1/309485009821345068724781056	1/309485009821345068724781056	1/309485009821345068724781056
1/618970019642690137449562112	1/618970019642690137449562112	1/618970019642690137449562112	1/618970019642690137449562112
1/1237940039285380274899124224	1/1237940039285380274899124224	1/1237940039285380274899124224	1/1237940039285380274899124224
1/2475880078570760549798248448	1/2475880078570760549798248448	1/2475880078570760549798248448	1/2475880078570760549798248448
1/4951760157141521099596496896	1/4951760157141521099596496896	1/4951760157141521099596496896	1/4951760157141521099596496896
1/9903520314283042199192993792	1/9903520314283042199192993792	1/9903520314283042199192993792	1/9903520314283042199192993792
1/19807040628566084398385987584	1/19807040628566084398385987584	1/19807040628566084398385987584	1/19807040628566084398385987584
1/39614081257132168796771975168	1/39614081257132168796771975168	1/39614081257132168796771975168	1/39614081257132168796771975168
1/79228162514264337593543950336	1/79228162514264337593543950336	1/79228162514264337593543950336	1/79228162514264337593543950336
1/158456325028528675187087900672	1/158456325028528675187087900672	1/158456325028528675187087900672	1/158456325028528675187087900672
1/316912650057057350374175801344	1/316912650057057350374175801344	1/316912650057057350374175801344	1/316912650057057350374175801344
1/633825300114114700748351602688	1/633825300114114700748351602688	1/633825300114114700748351602688	1/633825300114114700748351602688
1/1267650600228229401496703205376	1/1267650600228229401496703205376	1/1267650600228229401496703205376	1/1267650600228229401496703205376
1/2535301200456458802993406410752	1/2535301200456458802993406410752	1/2535301200456458802993406410752	1/2535301200456458802993406410752
1/5070602400912917605986812821504	1/5070602400912917605986812821504	1/5070602400912917605986812821504	1/5070602400912917605986812821504
1/10141204801825835211973625643008	1/10141204801825835211973625643008	1/10141204801825835211973625643008	1/10141204801825835211973625643008
1/20282409603651670423947251286016	1/20282409603651670423947251286016	1/20282409603651670423947251286016	1/20282409603651670423947251286016
1/40564819207303340847894502572032	1/40564819207303340847894502572032	1/40564819207303340847894502572032	1/40564819207303340847894502572032
1/81129638414606681695789005144064	1/81129638414606681695789005144064	1/81129638414606681695789005144064	1/81129638414606681695789005144064
1/162259276829213363391578010288128	1/162259276829213363391578010288128	1/162259276829213363391578010288128	1/162259276829213363391578010288128
1/324518553658426726783156020576256	1/324518553658426726783156020576256	1/324518553658426726783156020576256	1/324518553658426726783156020576256
1/649037107316853453566312041152512	1/649037107316853453566312041152512	1/649037107316853453566312041152512	1/649037107316853453566312041152512
1/1298074214633706907132624082305024	1/1298074214633706907132624082305024	1/1298074214633706907132624082305024	1/1298074214633706907132624082305024
1/2596148429267413814265248164610048	1/2596148429267413814265248164610048	1/2596148429267413814265248164610048	1/2596148429267413814265248164610048
1/5192296858534827628530496329220096	1/5192296858534827628530496329220096	1/5192296858534827628530496329220096	1/5192296858534827628530496329220096
1/10384593717069655257060992658440192	1/10384593717069655257060992658440192	1/10384593717069655257060992658440192	1/10384593717069655257060992658440192
1/20769187434139310514121985316880384	1/20769187434139310514121985316880384	1/20769187434139310514121985316880384	1/20769187434139310514121985316880384
1/41538374868278621028243970633760768	1/41538374868278621028243970633760768	1/41538374868278621028243970633760768	1/41538374868278621028243970633760768
1/83076749736557242056487941267521536	1/830767497365572420564879		



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**